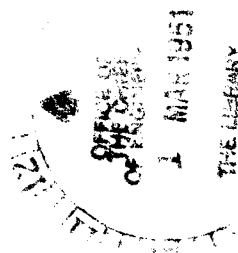


TA7
W34
no. 3-322

CORPS OF ENGINEERS, U. S. ARMY

**INVESTIGATION OF HEAVING OF FLOOR SLABS
OF BUILDING, FORT GULICK, PANAMA CANAL ZONE**



TECHNICAL MEMORANDUM NO. 3-322

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

JANUARY 1951

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JANUARY 1951

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Preface

This report describes an investigation of the heaving of a floor slab of a building at Fort Gulick, Panama Canal Zone, and contains recommendations for possible control of further upheavals.

A study of the soils in the critical area was conducted in accordance with a letter from the Office, Chief of Engineers, dated 29 Dec 1948, subject "Investigation of Floor Upheaval, Fort Gulick, Panama Canal Zone," requesting this investigation, and other correspondence from the Office, Chief of Engineers of the same date containing the results of an investigation made by the Geology Section, Panama Special Engineering Division.

This investigation was accomplished by the Soils and Concrete Research Divisions of the Waterways Experiment Station. Persons connected with the study were Mrs. K. Mather of the Concrete Research Division, and Messrs. W. J. Turnbull, S. J. Johnson, W. G. Shockley, J. E. Mitchell, and R. I. Kaufman of the Soils Division. This report was prepared by Mr. Kaufman. Additional analytical examinations were performed by Professor R. E. Grim, petrographer at the University of Illinois.

INVESTIGATION OF HEAVING OF FLOOR SLABS OF BUILDING

FORT GULICK, PANAMA CANAL ZONE

Introduction

1. The heaving of the floor slabs of a building at Fort Gulick was investigated by the Geology Section, Panama Special Engineering Division, in 1948 and the results suggested the following possible causes of the upheaval: swelling of the subgrade because of an increase in moisture content; elastic rebound; decrepitation by drying and oxidation of iron minerals; and stress due to folding or faulting. An additional report, entitled "Investigation of Heaved Floor Slabs of Buildings at Fort Gulick," 28 February 1949, by the Panama Engineer District Testing Laboratory, suggested that the upheaval was caused by either seasonal fluctuations in the moisture content of the soil composing the foundation, or possibly by the deposition and growth of crystals along the fracture planes in this material.

2. The purpose of this report is to present the results of the investigations conducted by the Waterways Experiment Station as to the cause of the heaving. The report includes the results of the various physical tests and petrographic analyses performed, and recommendations for reducing the amount of heave of the slabs.

Description of Samples

3. Two 5-in.-diameter core borings of Gatun sandstone were taken from Bldg 308 at Fort Gulick. These borings were located 24 in. apart,

and are referred to as holes nos. 1 and 2. The core boring logs, shown in plate 1, are copies of the logs furnished by the Headquarters, U. S. Army Caribbean. The core from hole no. 2 was used for physical tests; the core from hole no. 1 was subjected to a petrographic analysis.

Soils Classification Tests

4. The core boring logs refer to the soil as a sandstone. The samples tested, however, consisted of a hard, brittle, fossiliferous, grey, silty, bentonitic shale; therefore the term "shale" is used hereafter in this report. The sample showed some slight evidence of weathering as various fine cracks were present, although such cracks might have been caused by sampling. Visual observation revealed no variations in the sample with depth. It was also noted that drying a few fragments of the sample caused them to crack and shatter. The natural water content of the soil was about 40 per cent, and the corresponding degree of saturation was about 95 per cent.

5. Two specimens of the shale were subjected to routine classification tests. One specimen was from sample 7, at a mean depth of 26 in., and the other from sample 10 at a depth of 105 in. Atterberg limits tests were performed, and the liquid and plastic limits of the first sample were 72.5 and 46.0, respectively, while the corresponding limits of the second sample were 79.3 and 47.0. The natural water content of both samples was found to be approximately 41 per cent and the specific gravity of the solids was 2.71. The grain-size distribution curves were determined by mechanical analysis and are shown in plate 2. The results of the physical tests are listed in table 1.

Mineralogical Investigations

6. It became apparent that a more complete classification was essential in order to determine the swelling characteristics of the soil. Inasmuch as the type of clay minerals and exchangeable bases present in soil greatly influence its swelling properties, it was considered desirable to identify these constituents if they were present. Such an identification can be obtained from either a differential thermal analysis or a petrographic analysis of the soil. Both types of analyses were performed and are discussed in the following paragraphs.

Differential thermal analysis

7. Professor R. E. Grim, petrographer at the University of Illinois, performed the differential thermal analyses on four specimens from hole no. 2 designated cores 1, 2, 3, and 4. These cores corresponded to depths of 33, 70, 78, and 109 in., respectively. The results of these tests showed, for all four samples, a clay mineral component of the montmorillonite type, and the presence of an exchangeable base of a combination of sodium and calcium. Such a material might undergo large volume changes resulting from variations in water content, since as stated in Professor Grim's report, "montmorillonite..... has exceedingly high plastic and shrinkage properties and undergoes large volume changes due to variations in water content. These properties of montmorillonite are accentuated when Na (sodium) is present as the exchangeable base." The complete report, including the differential thermal curves, is included as Appendix B to this report.

Petrographic analysis

8. The core from hole no. 1 was subjected to a petrographic analysis in order to identify further the soil constituents. These tests verified the results obtained by Professor Grim. The tests showed no indication of crystalline growth along the fracture planes and hence eliminated the possibility "that a great part of the expansion of the rock was due to the deposition and growth, along the fracture planes, of crystals formed by the reaction of the lime in the rock with other chemical agents dissolved in the water."* The results of the detailed petrographic study are included as Appendix A of this report.

Swelling and Shrinkage Tests

Free swell tests

9. The relative sensitivity of the soil to swelling was determined by an empirical test known as the "free swell test." In this type test the soil is air-dried, broken down, and passed through a No. 28 but retained on a No. 48 Standard Tyler sieve. Ten cubic centimeters of this material are slowly dropped into a graduated cylinder containing 100 cc of water, and the new volume of the soil is then observed. The "free swell" is the volume increase expressed in per cent of the original 10 cc volume. The duration of this test should be about 30 minutes. In general, increases in volume of 40 per cent or greater would indicate that the soil is an expansive type. The "free swell" for the Gatun shale was found

* Panama Engineering District Testing Laboratory, "Investigation of Heaved Floor Slabs of Buildings at Fort Gulick," par. 6, February 1949.

to be 37 per cent, further indicating that this material might be sensitive to moisture changes.

Confined swell tests

10. It was decided to run swell tests in a manner that would most nearly duplicate conditions existing in the field in order to estimate the amount that the soil would swell when soaking up water. Two undisturbed specimens were selected for this purpose. One was taken from sample 7, beginning at a depth of 25 in.; the other was from sample 10, at a depth of 104 in. These specimens were placed in standard 4-1/4-in.-diameter by 1-in.-high consolidometer rings, the corresponding estimated overburden pressures were applied and the specimens were permitted to absorb water. The estimated overburden pressures applied were 0.140 and 0.502 tons per sq ft, respectively. Under this condition, sample 7 consolidated 0.0052 in., and sample 10 consolidated 0.0076 in. After the samples had completely consolidated, the previously applied normal loads were removed. The specimens were then permitted to swell under the tare weight of the upper porous stone and loading yoke, which correspond to a normal pressure of 0.015 tons per ft. Under this condition, sample 7 swelled 0.0014 in. and sample 10 swelled 0.0027 in. In terms of the volumes existing at the end of the initial consolidation, the increases in volume caused by absorption of water under the tare load were 0.14 and 0.27 per cent, respectively. The final degree of saturation for both samples was 100 per cent.

11. The volume change sensitivity of the soil when drying was obtained from an undisturbed specimen taken immediately below sample 7,

starting at a depth of 28 in., and trimmed to fit the consolidometer ring. This sample was called "7A". The specimen was placed in the consolidation device under the tare load and allowed to dry. The total change in volume, including changes in diameter as well as in height, from the natural condition to the air-dry condition was 5.44 per cent, while the change in volume due only to change in height was 1.18 per cent. The results of these tests are shown in table 1. Thus for the material at a depth of 28 in. to 33 in. the total increase in height to be expected, when the air-dry sample becomes completely saturated, amounts to 1.32 per cent. If the zone in which moisture changes occur is 3 ft deep as the previous reports indicate, the total change in height to be expected would be about 0.5 in. This heave is considerably less than the recorded expansions obtained either at the site or in the Panama Engineer District Testing Laboratory.

Cyclic swell and shrinkage tests

12. In addition to the above tests, cyclic swell and shrinkage tests were performed on three undisturbed specimens, which were designated 7BU, 7BL, and 10A. The corresponding depths from which the samples were taken were 35 in., 38 in., and 100 in. These specimens were placed in 4-1/4-in.-diameter by 1-1/4-in.-high consolidometer rings and under the tare load of the consolidometer (0.015 tons per sq ft) were permitted to soak. After the specimen had stopped swelling, the consolidometer was weighed and the vertical dial reading was recorded. The samples were then dried by placing the consolidometers on a hot plate at 150 C. After the samples had dried, the vertical dial readings and weights were recorded.

The above procedure was repeated until 2-1/2 cycles had been completed, the duration of a cycle being approximately 63 days.

13. The results of these tests are plotted on plate 3, and are tabulated in table 2. They show that, as the number of cycles is increased, a corresponding increase in specimen height results. For example, when the undisturbed specimen was permitted to soak until saturated, only a slight increase in height resulted; however, after the specimen had then dried and been re-soaked, the corresponding height at the end of the saturation process was considerably greater than that existing after the sample had been soaked for the first time. The height corresponding to the completion of the third soaking was again greater than the previous heights. From plate 3 it can also be seen that the specimen, on drying, did not return to the height existing after it had dried the first time; instead, at the end of each of the "dry" cycles the height was greater than that for the previous "dry" cycle. Thus it is concluded that alternate wetting and drying of the Gatun shale causes a progressive heave of the material. However, a sufficient number of wetting and drying cycles was not completed to determine when stabilization would occur.

14. Another series of tests was performed on three undisturbed samples of shale about 2 in. in diameter by 2-1/2 in. high. The samples were taken at depths of 41, 44, and 107 in. and were labeled 7CU, 7CL, and 10B, respectively. These specimens were grouted into 3-1/2-in.-diameter by 2-in.-high tins with plaster of paris so that the annular space between the soil and tin was completely filled. The initial weight of the specimen was determined, then holes were bored in the bottoms of the tins and through the grout so that drainage paths were present, after

which the vertical dial reading corresponding to the initial specimen height was determined. The weight of the specimen plus tare was also recorded. The tins were placed on top of an oven and the samples were permitted to dry. After the samples had dried completely, the weight and dial readings were determined. The tins were then placed in a saturated sand bath and the soil was allowed to absorb moisture and swell under a vertical normal pressure of 100 lb per sq ft. When no further swelling took place, the dial reading and weight were again recorded. After removing the normal load, the tins were again placed on top of the oven. The above procedure was repeated until three cycles had been completed. The moisture contents were computed from the oven-dry weight of the soil plus tare determined at the end of the test, and the tare weight of the tin and grout.

15. The results of these tests, which appear in table 3, and are plotted on plate 4, are quite similar to the results obtained on the samples placed in consolidometers. Again there is a progressive expansion, so that the specimen height at the end of soaking is always greater than any previous height. However, since these specimens heaved under a vertical-normal pressure of 100 lb per sq ft, the amount of volume change occurring was less than that for the samples subjected to 0.015 tons per sq ft (30 lb per sq ft) in the consolidometers. The average final maximum volume increase was 4.4 per cent for the samples grouted in tins, and 14.4 per cent for the samples in the consolidometers. Again the number of cycles required for stabilization was not determined.

Summary and Conclusions

16. The results of tests performed show that the Gatun shale contains a montmorillonite-type clay mineral with an exchangeable base composed of sodium and calcium. Such a material inherently is extremely sensitive to volume changes caused by variations in moisture conditions. Meanwhile, no evidence of crystalline growth along the fracture planes was found. The cyclic swell and shrinkage tests show that the shale experienced large volume changes with varying moisture content, and it is believed that the upheaval of the floor slabs at Fort Gulick is caused by the seasonal variations of the moisture in the shale beneath the floor slab.

17. An analysis of the heave, based upon the results of the cyclic tests, shows that at the end of 2-1/2 cycles a heave of about 1.0 in. can be expected for the 3-ft zone of variable moisture. However, if the number of cycles increases, the amount of heave probably would increase also, inasmuch as the data on plates 3 and 4 show that the heave probably continues with the number of moisture cycles, up to a certain undetermined point.

Recommendations

18. The following recommendations for preventing additional heave are submitted in view of the fact that the heaving of the Gatun shale appears to be a result of the effect of the changes in water content upon the montmorillonite present:

- a. Excavate the material to a depth at which there are no seasonal variations in moisture content and then backfill with a compacted free-draining sand and gravel mixture. The depth to which excavation should be carried would largely determine the feasibility of this procedure. It

may be sufficient to excavate 2 to 3 ft to attain the desired result. However, it is felt that the depth of the fractured upper zone of material is not necessarily indicative of the limit of water-table fluctuation and some swelling may occur in the lower unfractured material. Observations of ground-water level over a period of a year or so would be the best indication of its probable maximum depth.

- b. Prevent the cyclic changes in moisture content by constructing a gravel-filled trench around the building and by keeping the trench saturated at all times.
- c. Inasmuch as the existing footings have not moved, reconstruct the floor slabs so that they carry the loads directly to the footing columns and do not bear on the ground, if the footings can take this additional load. Soil under the floor slab should be excavated to a sufficient depth to provide a clear space of several inches between the foundation and the floor slab system.

19. It is believed that any one of the three methods outlined in the above recommendations would provide a solution to the problem of floor slab heaving; the choice would depend largely upon the economic considerations involved although alternates a and c appear preferable to alternate b.

Table 1

RESULTS OF SWELL TESTS ON GATUN SHALE

Sample No.	Depth in.	LL	PI	Consol. Press. T/sq ft	Sample Height			Diameter		Volume Change, %		Water Content %	
					Initial in.	Final in.	Change %	Initial in.	Final in.	Vertical	Total	Initial	Final
7	25-28	72.5	26.5	0.140	1.0000	0.9948	-0.52	4.250	4.250	-0.52*	-0.52	41.2	-
		-	-	0.015	0.9948	0.9962	+0.14	4.250	4.250	+0.14	+0.14	-	42.3
7A	28-31	-	-	0.015	1.2500	1.2352	-1.18	4.250	4.158	-1.18	-5.44	35.6	8.7
10	104-109	79.3	32.3	0.502	1.0000	0.9924	-0.76	4.250	4.250	-0.76	-0.76	40.1	-
		-	-	0.015	0.9924	0.9951	+0.27	4.250	4.250	+0.27	+0.27	-	41.9

* Note: "+" indicates an increase in height and volume.

Table 2

RESULTS OF CYCLIC SWELL AND SHRINKAGE TESTS

ON SPECIMENS IN CONSOLIDOMETERS

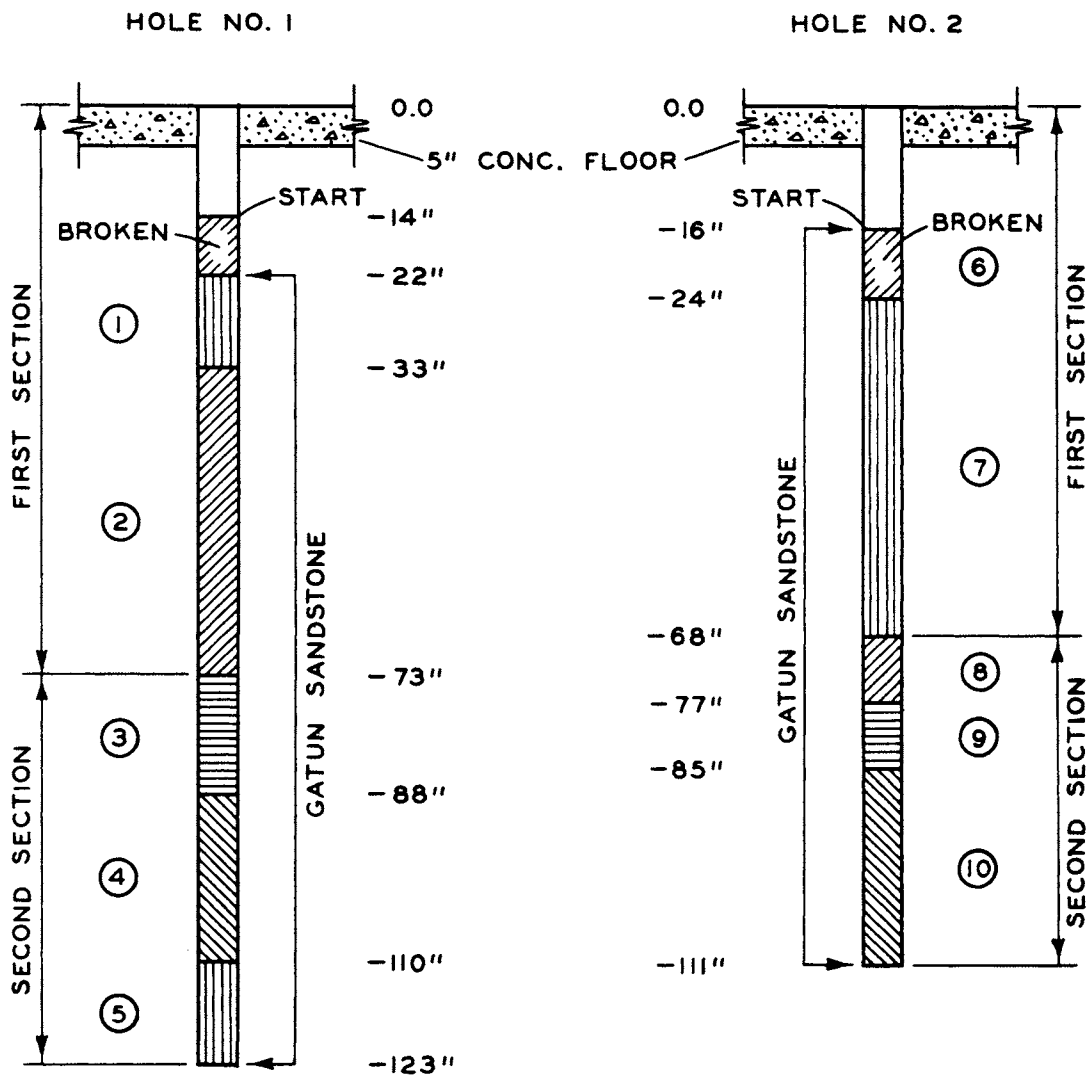
<u>Sample No.</u>	<u>Moisture Condition</u>	<u>Height in.</u>	<u>Volume Change %</u>	<u>Water Content %</u>	<u>Consol. Press. T/sq ft</u>
7BU	Natural	1.2500	0.0	47.2	0.015
	Wet	1.2504	0.03	49.2	0.015
	Dry	1.2277	-1.79	0	0.015
	Wet	1.3551	8.42	54.4	0.015
	Dry	1.2970	3.76	1.7	0.015
	Wet	1.4172	13.38	54.4	0.015
	Dry	1.3372	6.96	0.3	0.015
7BL	Natural	1.2500	0.0	39.2	0.015
	Wet	1.2505	0.04	39.7	0.015
	Dry	1.2433	-0.54	1.5	0.015
	Wet	1.3075	4.60	50.6	0.015
	Dry	1.2775	2.20	2.0	0.015
	Wet	1.4416	15.31	50.6	0.015
	Dry	1.3885	11.07	1.5	0.015
10A	Natural	1.2500	0.0	50.5	0.015
	Wet	1.2504	0.03	54.3	0.015
	Dry	1.2290	-1.68	0	0.015
	Wet	1.3183	5.46	56.5	0.015
	Dry	1.2692	1.53	0.0	0.015
	Wet	1.4323	14.59	57.3	0.015
	Dry	1.3405	7.24	1.1	0.015

Table 3

RESULTS OF CYCLIC SWELL AND SHRINKAGE TESTS

ON SPECIMENS GROUTED INTO TINS

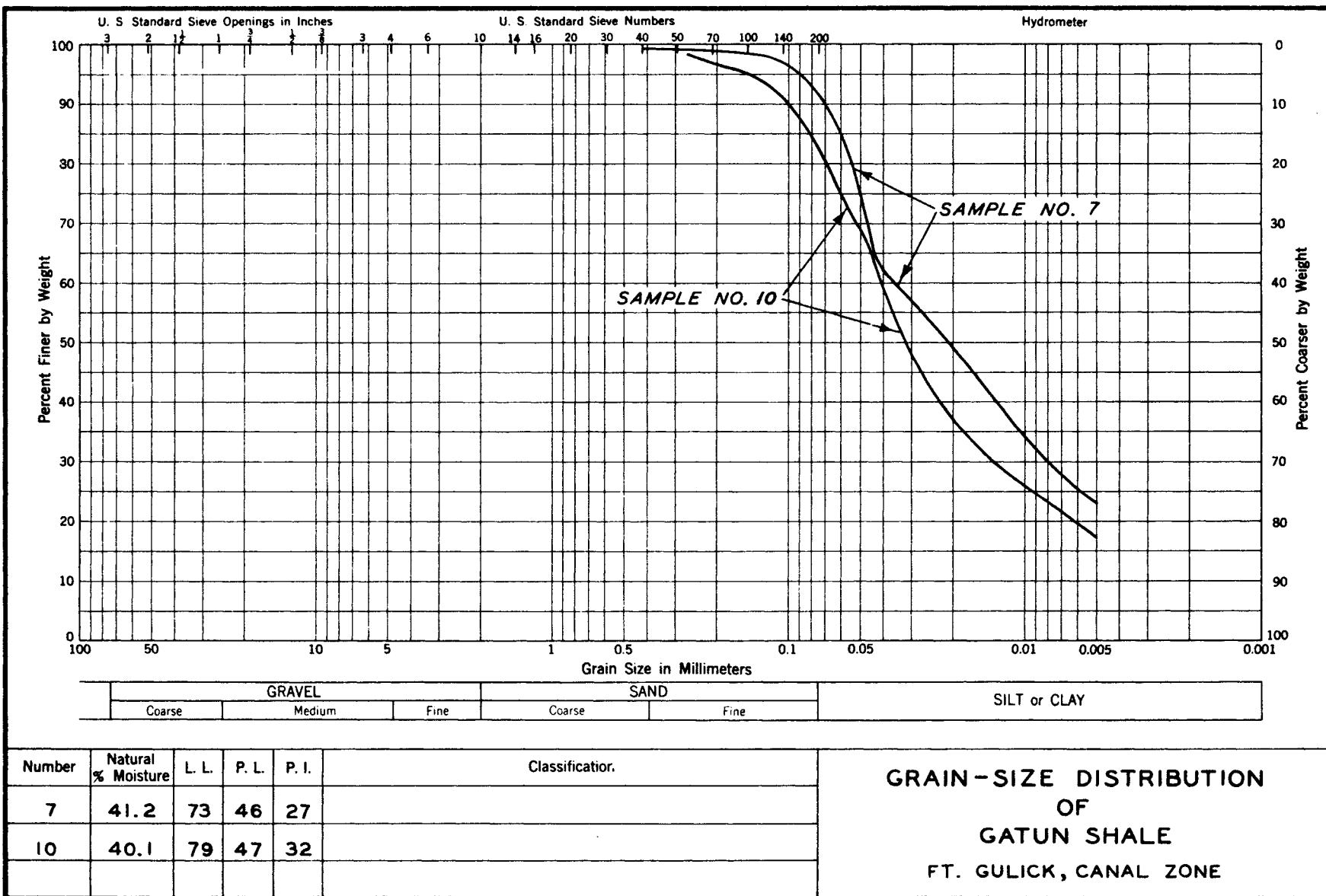
<u>Sample No.</u>	<u>Moisture Condition</u>	<u>Consol. Press. lb/sq ft</u>	<u>Height in.</u>	<u>Volume Change %</u>	<u>Water Content %</u>
7CL	Natural	0	2.5709	0	51.1
	Dry	0	2.5339	-1.4	7.1
	Wet	100	2.6511	3.1	58.6
	Dry	0	2.6058	1.4	1.1
	Wet	100	2.6719	3.9	60.2
	Dry	0	2.6436	2.8	4.1
7CU	Natural	0	2.4449	0	48.9
	Dry	0	2.3803	-2.6	4.8
	Wet	100	2.5031	2.4	58.0
	Dry	0	2.4833	1.6	0.9
	Wet	100	2.5489	4.3	60.5
	Dry	0	2.5421	4.0	1.7
10B	Natural	0	2.5276	0	54.3
	Dry	0	2.4856	-1.7	6.7
	Wet	100	2.6065	3.1	60.6
	Dry	0	2.5777	2.0	1.0
	Wet	100	2.6565	5.1	62.6
	Dry	0	2.6228	3.8	3.8

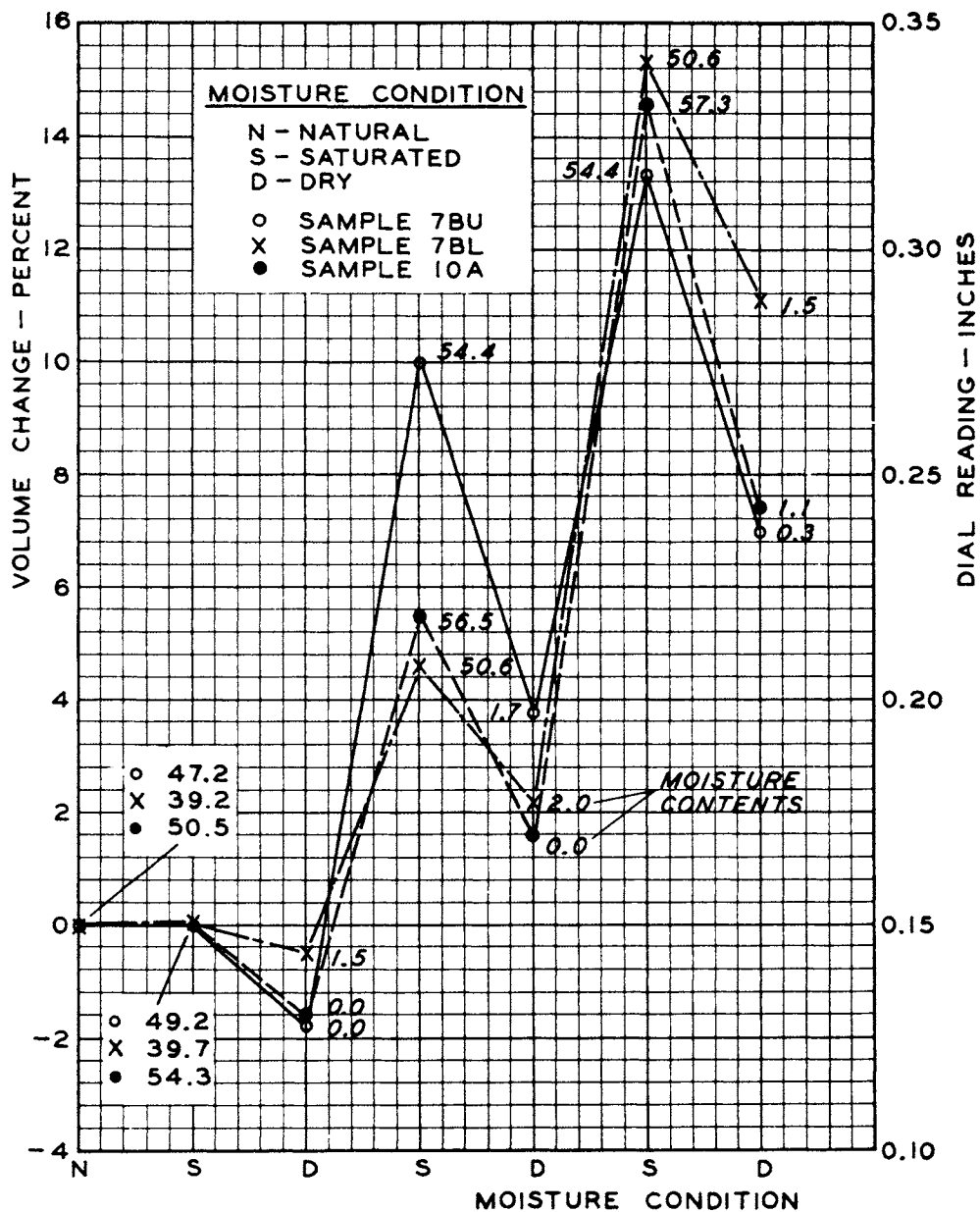


LEGEND:

⑦ MARKINGS ON SAMPLES

CORE BORING LOGS
SAMPLES TAKEN FROM BLDG. 308, FORT GULICK, C. Z.





RESULTS OF CYCLIC WETTING AND DRYING
TESTS ON GATUN SHALE SAMPLES
PLACED IN CONSOLIDOMETERS

Appendix A

Petrographic Report

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PETROGRAPHIC
REPORT

CONCRETE RESEARCH
DIVISION
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CLINTON, MISSISSIPPI

SYMBOL:	PROJECT:	DATE REPORT	INITIALS
PAN-2 3200.	Ft. Gulick, Panama	SUBMITTED: 16 Jan 1950	KM
SERIAL NO:	SOURCE: Drilled core from depths 22 in. to 123 in.		
PAN-2 G-1	below top of floor slab, Building 308, Ft. Gulick, Canal Zone		

1. Samples. On 15 July 1949 approximately 10 ft of 5-in. drilled core was received from the office of the Commanding General, Headquarters, U. S. Army Caribbean. Correspondence from that office dated 15 June 1949 stated that the core was one of two from drill holes located 24 in. apart through the floor slab and substrata in Building 308, Fort Gulick, Canal Zone. The log of the two holes indicated that the core received was that from hole No. 1. CRD Serial No. Pan-2 G-1 was assigned to the sample; the core log (plate 1) shows the location of breaks and the numbers assigned to the sections by the Panama District. A memorandum from the Chief, Embankment and Foundations Branch, Soils Division requested petrographic determinations of the clay minerals in the core, and examination to determine whether expansion of the rock could have been caused by the growth of crystals in fracture planes.

2. Summary. Petrographic examination has been made of approximately 10 ft of core from depths 22 to 123 in. representing the substrata beneath Building 308, Fort Gulick, Canal Zone. Except for about 1/2 inch at the top of section 1, and parts of sections 3 and 4, the core as received represented unexpanded material. Core sections 3 and 4 were removed intact from the drill hole and flaked and cracked after they were wrapped in burlap and paraffin, probably because the burlap took up moisture from the core. When the core was removed from the burlap and paraffin cover, it appeared to be soft but coherent fossiliferous silty shale. As the cores dry, they lose coherence and fracture and crumble easily. Determinations were made of the indices of refraction of the clay portion of core sections from depths 32 - 33, 73 - 76, 110 - 111, and 122 - 123 in. The clay mineral was crystalline and had aggregate indices of refraction ranging from slightly above 1.49 to slightly below 1.52. These values are below those of the crystalline members of the kaolin group and within the range of the montmorillonite-beidellite series as measured on materials of high water content, and reinforce the determinations of montmorillonite by thermal analysis. The rock contains crystals and knots of iron sulfide (probably marcasite), most of them located in or near fragments of fossil plants. The iron sulfide is fresh and unoxidized. Portions of the core

COPY

COPY

<u>PETROGRAPHIC REPORT (CONT'D)</u>	SYMBOL:	SERIAL NO:	DATE:
	PAN-2 3200	PAN-2 G-1	16 Jan 1950

contain small crystals and rosettes of gypsum (Photograph A1) but the size, distribution, and habit of the crystals indicate that they grew on open fracture planes and did not cause the fractures by their growth. The rock in the cores is fossiliferous marine silty bentonitic shale, containing large amounts of clay of the montmorillonite group. The crystal lattice of montmorillonite is built up of stacks of silicate layers of great lateral extent compared to their thickness (Ross and Hendricks, USGS Prof. Paper 205 B, 1945, pp 29, 30). Montmorillonite possesses a unique property of taking water up between the silicate layers and swelling as a result of this increase in water content; the expansion in the crystal lattice of a unit flake from dry to completely hydrated more than doubles the thickness of the flake (Paul Bechtner, Bentonite, Chapter 5 in Industrial Minerals and Rocks, Second Edition, 1949, American Institute of Mining and Metallurgical Engineers). The general orientation of the montmorillonite flakes in a bedded rock such as the Gatun formation can be expected to be roughly parallel to the bedding, either as a result of deposition or later rearrangement under pressure of overlying sediments. Such considerations would help to account for the tendency of the subgrade of the warehouses to swell more vertically than laterally. The tendency of montmorillonite to swell is greatly increased if the clay has first been dehydrated; it is reported that montmorillonite clay beds swell, heave, and flow enough to produce apparent changes in geologic structure only after dehydration (G. A. Schroter and I. Campbell, Geological Features of Some Deposits of Bleaching Clay, Trans. A.I.M.E., vol 148, 1942, pp 186 - 188). Those aspects of the history and situation of the warehouses which bear on the opportunities of the subgrade to dry out are therefore important in an explanation of the heaving.

2 Incls.

1. Detailed Petrography
2. Photograph A1

COPY

COPY

	SYMBOL:	SERIAL NO:	DATE:
PETROGRAPHIC REPORT (CONT'D)	PAN-2 3200	PAN-2 G-1	16 Jan 1950

Detailed Petrography

1. Test procedure. The core sections as received had been wrapped in burlap and coated with paraffin to preserve the original moisture content. On 25 October 1949 the paraffin and burlap were cut away from a strip about 3 in. wide and 8 in. long on core section 1 from depths 22 - 33 in., and the exposed surface was examined visually and with a stereoscopic microscope. A small amount of the core was scraped out with a knife blade, powdered, mounted in immersion oil, and examined using the petrographic microscope. Core section 1 was left with the surface partially exposed to laboratory air until 16 December when it was re-examined, and the rest of the paraffin and burlap removed. The other core sections were stripped, examined, and exposed to laboratory air for varying periods. Spalls were broken from the core with a chisel-ended hammer, examined under the stereoscopic microscope, and immersion mounts prepared from selected areas for examination using the petrographic microscope. One fragment from core section 1 was impregnated with resin and three thin sections prepared and examined. Several photographs were made.

2. Description of cores.

a. Megascopic examination. When the cores were first unwrapped, they were dark gray, slightly damp, coherent, fine-grained soft rock resembling shale. About 1/2 in. of the top of section 1 had separated into thin flakes along planes parallel to the bedding. Section 3 broke on unwrapping at a point representing a depth of about 76 in. The rock from 73 to 76 in. was highly flaked and fractured. Section 4 which was 22 in. long collapsed as it was being carried from the core box to a table to be unwrapped, and broke into two sections, one about 8 and the other 10 in. long. The rest of the core in section 4 consisted of flakes. Except for the flaked areas, the core as unwrapped was massive and coherent and did not split or flake easily. As the cores dried in air, they cracked. Most of the cracks followed the bedding direction, but were interconnected by cracks roughly normal to the bedding. As small pieces spalled from the cores dried in air, they flaked more easily parallel to the bedding. As sections up to 2-in. thick dried in laboratory air over a period of weeks, they lost all coherence and crumbled easily. Several core sections developed long cracks almost parallel to the long axis of the core on what appeared to be pre-existing joint directions which were not apparent in the cores as unwrapped.

b. Examination of broken surfaces. Under the stereoscopic microscope the rock shows a rough bedding, made apparent by subparallel arrangement of white fossil shells and brown to black fossil plant fragments. The fossil shells include pelecypods and sea-urchin fragments up

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to 1/2 in. in maximum dimension, gastropods up to 3/4 in. in maximum dimension, and very abundant small gastropods, pelecypods, and foraminifera. The plant material and the marine fossils vary in abundance and degree of parallel orientation over small vertical and horizontal distances. A few areas up to 1 in. by 2 in. contain fossil shells or plant fragments as the major constituent of the rock; some parts of the core are only sparsely fossiliferous. On the average, any area 1 in. by 1 in. parallel to or normal to the bedding contains brown or black plant and white shell fragments visible to the naked eye. Rounded patches of fluffy white to pale green clayey material were found on broken surfaces of section 4. Powder mounts of the clay were prepared and found to consist of quite pure montmorillonite with small amounts of ferromagnesian and opaque minerals. It is believed that the patches represent fragments of volcanic rock altered after the deposition of the sediment. The groundmass of the rock is gray and structureless at magnifications up to 60X. In those sections of the core which were massive and unfractured when they were unwrapped, there is no evidence that any expansion of the material has taken place. Delicate fossils which break at the touch of a needle are entire; no fractures can be found except those produced in breaking the core with a hammer.

In the flaked sections (top of No. 1, several parts of No. 3, top of No. 4) there are small rosettes and single crystals of gypsum growing on the fracture planes (Photograph A1). The habit, distribution, and amount of the gypsum indicate that the crystal groups formed after the fracture planes had opened, and were not the cause of their formation. Small crystals, crystal groups, and knots of granular iron sulfide (probably marcasite) are commonly associated with the fossil plant fragments, were found in the unfilled interior of one high-spined gastropod, and are disseminated in the groundmass of the rock. The sulfide is fresh and apparently unoxidized.

c. Examination of immersion mounts. Immersion mounts were prepared from pieces of the core from depths 32 - 33 in., 73 - 76 in., 110 - 111 in., and 122 - 123 in. Clay minerals were found in all of the immersion mounts. The clay was present as birefringent aggregates of small flakes; the indices of refraction of the aggregates varied but were below 1.52 and above 1.49. The determinations of index were on samples obtained by soaking small pieces of the core in water or dilute ammonia stirring up the material loosened by soaking, allowing the coarser particles to settle and catching the finer material on a glass slide suspended in the water. Slides prepared in this way were allowed to dry in air for a few hours; immersion oil was added, the slide was covered and the index of refraction of the clay compared with that of the oil. The liquids used were mixtures

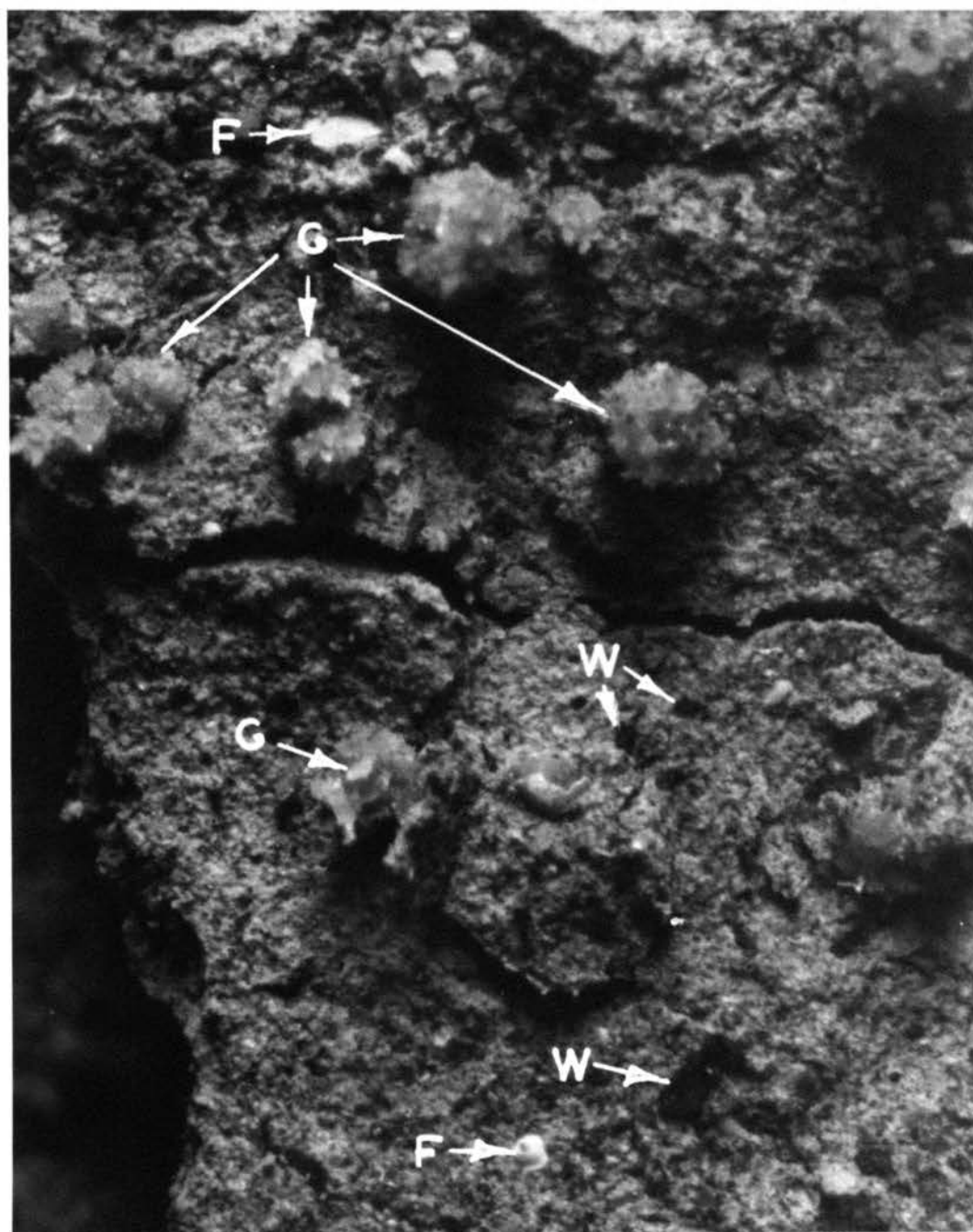
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of mineral oil and alphachloromaphthalene. The indices obtained by these means fall below those of the anisotropic members of the kaolin group as given by Rogers and Kerr⁽¹⁾ and within the montmorillonite-beidellite range as reported by the same authors. A study of the literature available indicates that the indices of refraction of the kaolin minerals are constant at normal temperatures. The montmorillonite minerals, on the contrary, have less stable crystal structure, and their optical properties vary widely with changes in chemical composition and water content, and may be altered by the immersion media used. The indices decrease with increasing water content. It is believed that the method described above gave indices determined on clay with a fairly high water content. While optical methods are not reliable by themselves in determinations of the clay minerals, the information obtained does agree with and confirm the results of the thermal analyses.

d. Examination of thin section. Study of the thin section prepared from part of core section 1 showed that the rock consisted of conspicuous marine fossils, fragments of fossil wood, feldspar, igneous rock, and quartz in a matrix of clay and small calcite grains. The clayey matrix and silt-size feldspar grains appear to be the most abundant constituents. On the basis of composition, grain size, and the evidences of origin provided by the organic remains, the rock may be classified as fossiliferous marine silty bentonitic shale.

(1) Rogers and Kerr, Optical Mineralogy, second edition 1942, p. 354.



BROKEN SURFACE OF FLAKED CORE, X25, SHOWING ROSETTES OF GYPSUM CRYSTALS (G), FRAGMENTS OF FOSSIL SHELLS (F), AND FOSSIL WOOD (W).

SECTION 4, CORE NO. 1, FT GULICK, PANAMA CANAL ZONE

Appendix B

Differential Thermal Analyses of Rock

Core Samples From Fort Gulick

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August 12 1949

Report on Differential Thermal Analyses of rock core samples from Fort Gulick, Panama Canal Zone. Analyses made for the Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi as per Order #14,609.

The samples analysed were labeled as follows:

Core #1
Core #2
Core #3
Core #4

A preliminary microscopic examination of the samples indicated that they contained considerable amounts of non-clay in the form of quartz and calcite grains, fragments of amorphous siliceous or glassy material, and organic material.

In order to get a satisfactory determination of the composition of the clay material, it was necessary to concentrate the clay material. This was done by dispersing the core material in distilled water with ammonia as the dispersing agent and then separating by decantation the fraction smaller than two microns. Following the separation of the minus two micron fraction, the organic material was removed therefrom by hydrogen peroxide. The differential thermal analyses were made on the minus two micron fraction so separated.

The differential thermal curves are enclosed herewith. They are all substantially the same and indicate that the clay mineral component is a montmorillonite type mineral. No other clay mineral is indicated. The montmorillonite is probably not too well crystallized and is probably the variety with a considerable amount of iron in its composition.

The initial endothermic peak between about 100 and 200 C, due to the loss of adsorbed water, varies somewhat from core to core probably indicating some slight variation in the character of the exchangeable base in the various cores. Based on the shape of this initial peak, the cores probably carry both Na and Ca as exchangeable bases with the Na relatively greatest in core #1.

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The pronounced endothermic depression in #4 at about 700 C suggests that this core has the largest relative amount of well crystallized montmorillonite.

Of considerable interest is the fact that only curves for #1 and #2 show any carbonate (indicated by the small sharp endothermic peak at about 750 C) whereas the cores as a whole have considerable carbonate. All of the carbonate is in the size fractions coarser than the clay.

Montmorillonite is the constituent of bentonites. It has exceedingly high plastic and shrinkage properties and undergoes large volume changes due to variations in water content. These properties of montmorillonite are accentuated when Na is present as the exchangeable base.

A cursory microscopic examination of the core samples showed them to have large concentrations in the fine silt size of quartz, carbonate, siliceous, and glassy material. In recent years I have had occasion to make numerous analyses of soils outstanding for their lack of stability. In many cases a concentration of silt was a prominent attribute.

The cores also contain a considerable amount of organic material which would also tend to augment their plastic properties.

COPY

Sample #1 Fort Gullick P.C.Z.

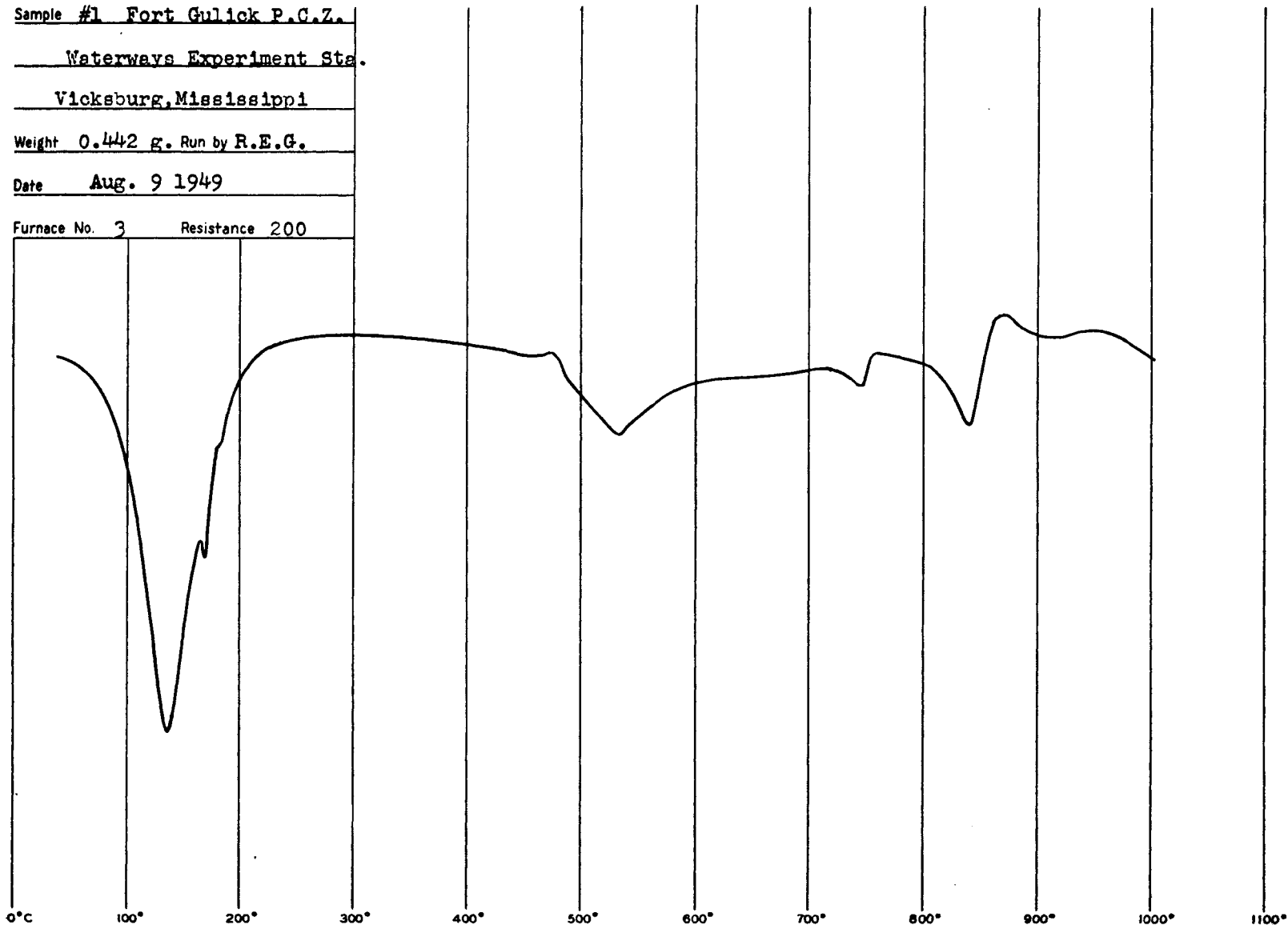
Waterways Experiment Sta.

Vicksburg, Mississippi

Weight 0.442 g. Run by R.E.G.

Date Aug. 9 1949

Furnace No. 3 Resistance 200



Core No. 1

Sample #2 Fort Gulick P.C.Z.

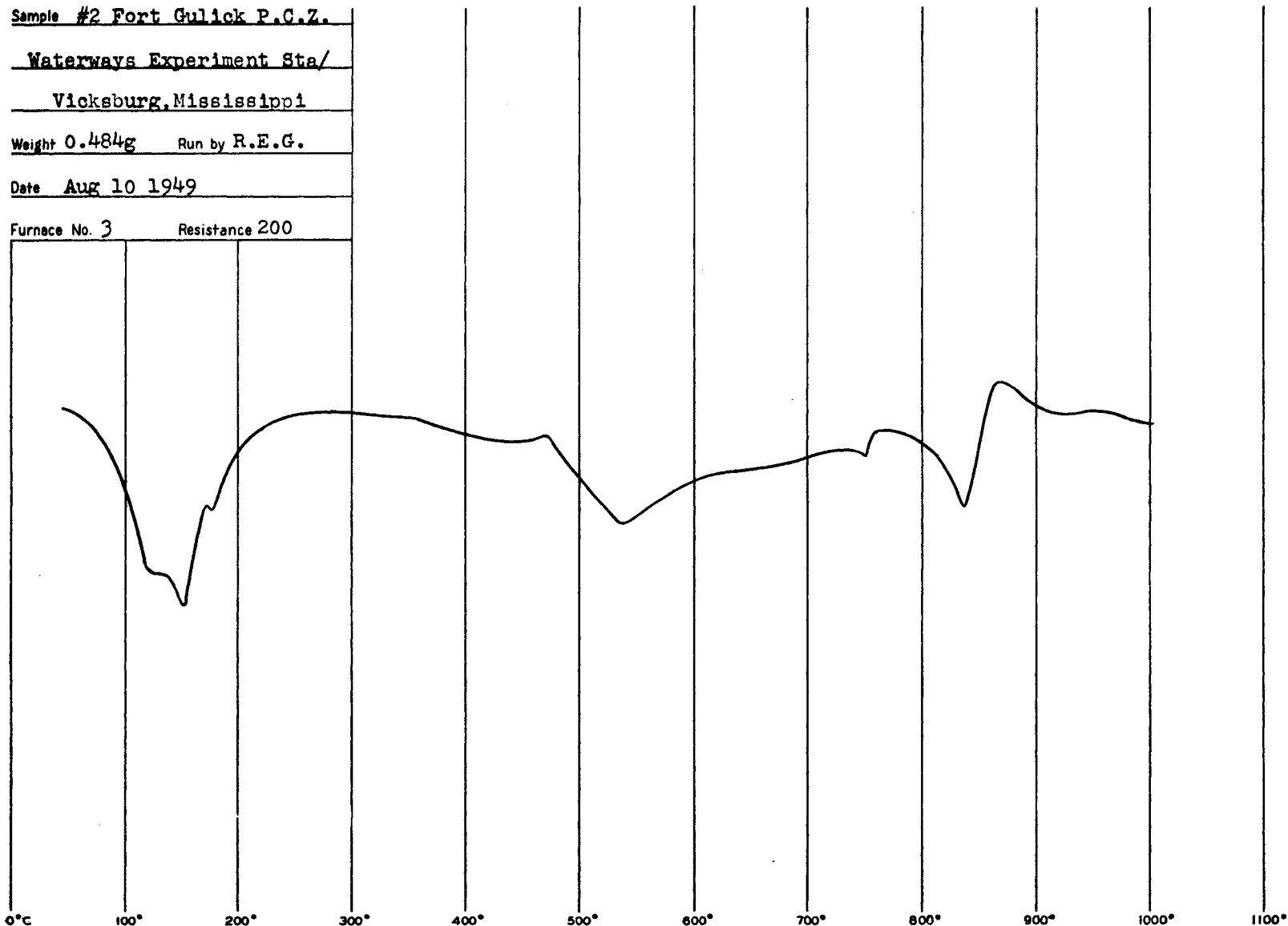
Waterways Experiment Sta/

Vicksburg, Mississippi

Weight 0.484g Run by R.E.G.

Date Aug 10 1949

Furnace No. 3 Resistance 200



Core No. 2

Sample #3 Fort Gulick P.C.Z.

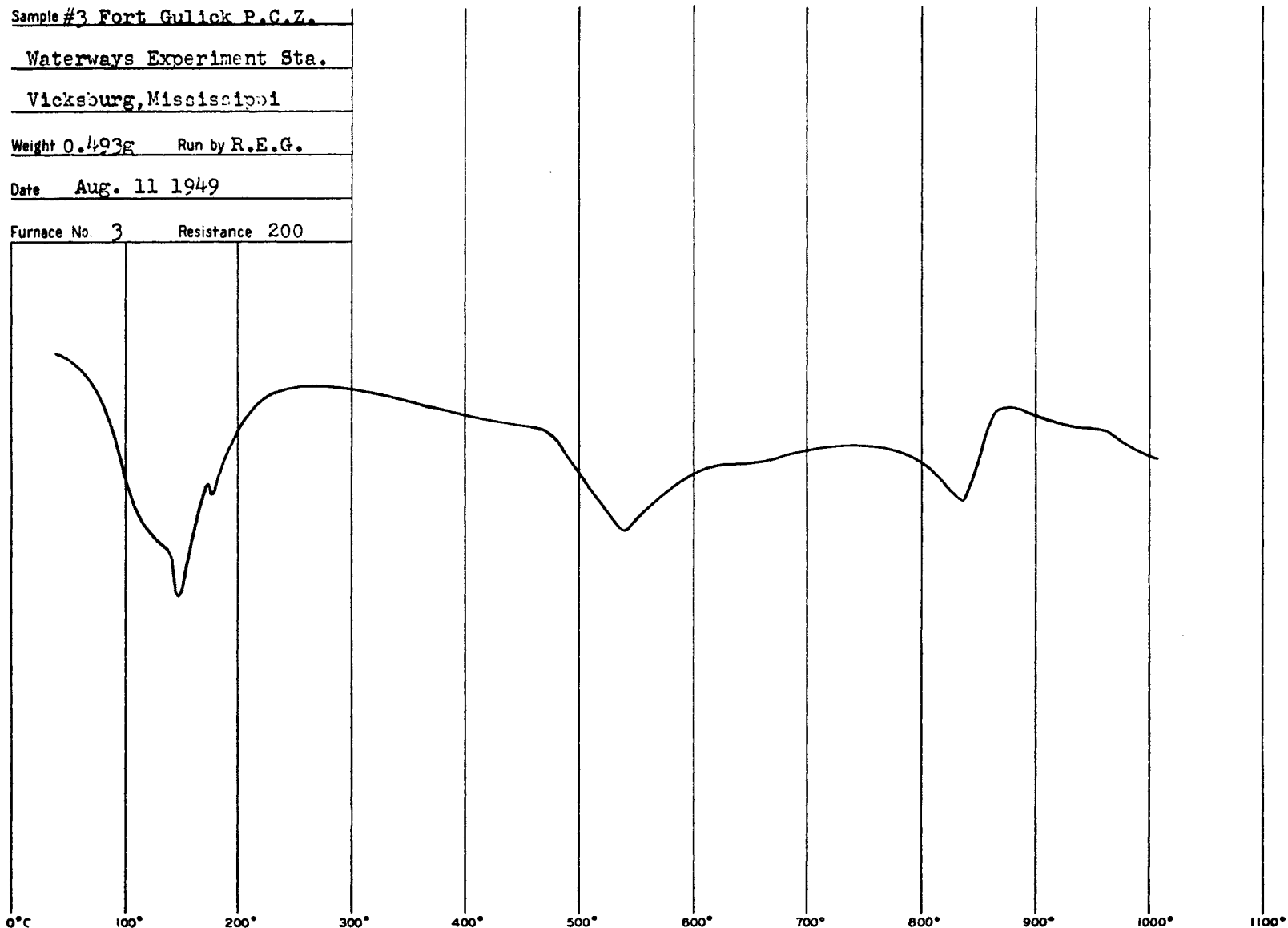
Waterways Experiment Sta.

Vicksburg, Mississippi

Weight 0.493g Run by R.E.G.

Date Aug. 11 1949

Furnace No. 3 Resistance 200



Core No. 3

Sample #4 Fort Gulick P.C.Z.

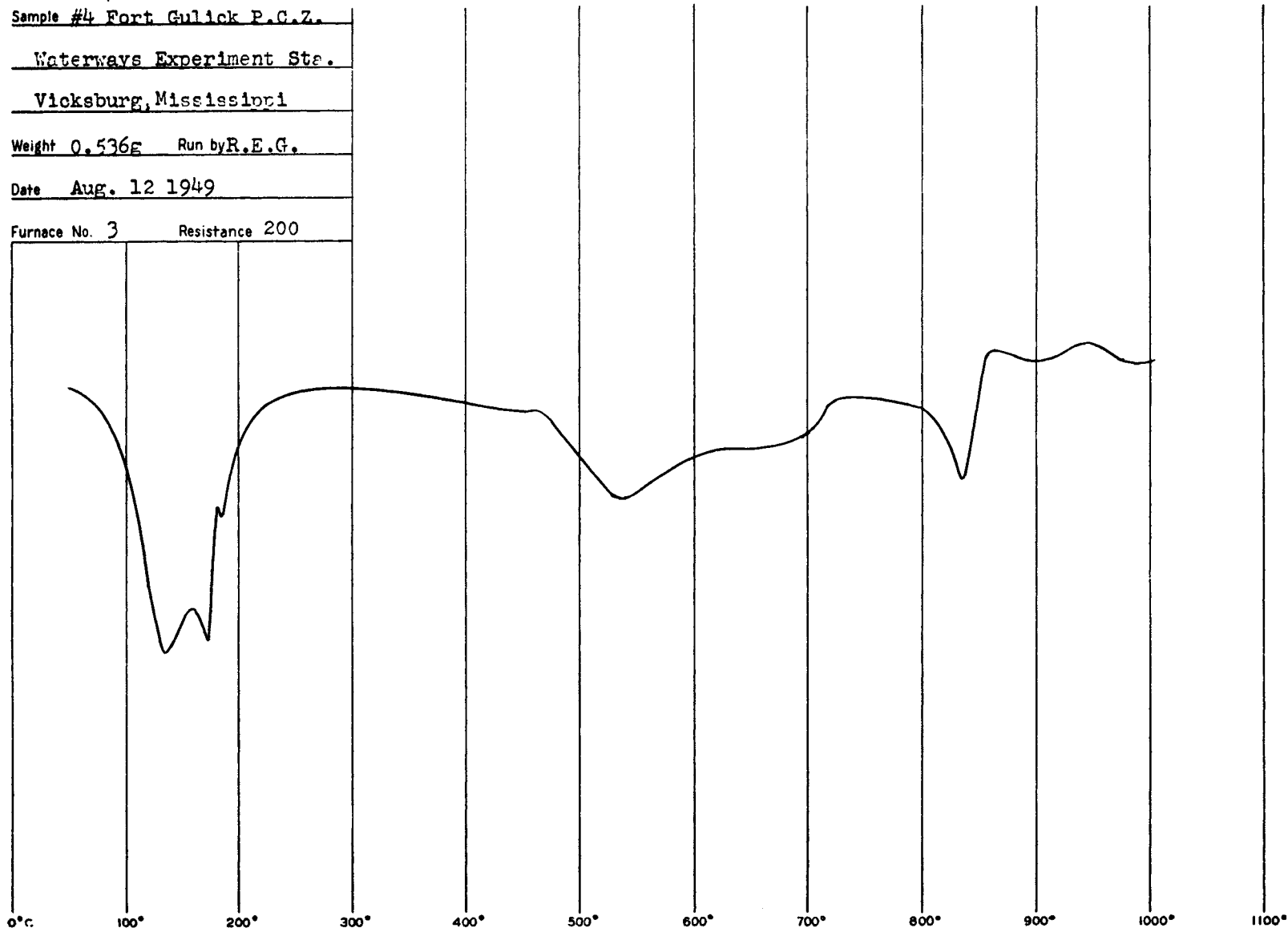
Waterways Experiment Sta.

Vicksburg, Mississippi

Weight 0.536g Run by R.E.G.

Date Aug. 12 1949

Furnace No. 3 Resistance 200



Core No. 4